Adaptive Fuzzy Tuned PID and UPFC for Reactive Power Compensation in Distributed Generation System

Asit Mohanty[1], Soumya R. Mohanty[2], Nand Kishor[3], Prakash K. Ray[*]

[1]Research Scholar, MNNIT Allahabad, [2] Asst Prof. MNNIT Allahabad,[3]Associate Professor.MNNITAllahabad,*AsstProfessorIIITBhubaneswar

***Abstract*-Self tuned Fuzzy logic based PID controller is developed in this paper to regulate the reactive power of a decentralized wind-diesel hybrid power system under different disturbance conditions. The study incorporating small signal analysis has been taken. The linearized model of wind, diesel is used where IEEE Excitation system (type-1) with synchronous generator is taken into account. Due to the abrupt load changes and sporadic nature of wind, reactive power and voltage stability problem occur. For the above problem, a Auto tuned Fuzzy Logic PID (STFLPID) controller is designed, which automatically tunes the coefficients of PID controller (KP and Ki). From Simulation it shows that the proposed controller attains the steady state value with less settling time and overshoot for a wide and unpredicted load changes and thereby proves it's superiority.**

Keywords- Reactive power control, Self Tuned Fuzzy Logic PID Controller, Hybrid power system, IG, UPFC

I. INTRODUCTION

Looking into the increasing demand of electricity, increase in fuel price, depletion of fossil fuels, increased environmental pollution are the main reasons for which power engineers and researchers are focusing on alternating power generations and renewable. The main reason behind the popularity of Renewable energy source is primarily due to their pollution-free, abundant characteristics along with the increased chance of availability of power at remote locations. But the major drawback is their highly variable/intermittent nature. To improve the quality of the power supply of grids, the renewable energy sources like wind, photovoltaic, small hydro, fuel cell along with energy storage devices like battery, flywheel, ultra-capacitors etc. are integrated to form hybrid system. Diesel generators play a vital part in the system which compensates the shortage of power to meet the load demand. In many places the Renewable sources act with the conventional sources and are widely known as Autonomous hybrid power systems [1]-[2]. Normally a Synchronous generator is used as Diesel Generator and Induction Generator is used in Wind Turbine. [3]-[5] for an improved performance. Induction generators are often advantageous than synchronous generators in a hybrid power system but it badly needs reactive power for its operation. Though Synchronous generator provides reactive power to the Induction Generator, but there is always short fall of reactive power in the system. Due to this big gap between demand and supply of reactive power, serious problem like voltage fluctuation occurs. This leads to voltage instability in the hybrid power system.

Detailed literature survey from [6]-[16] shows the need to improve and compensate the reactive-power and manage the Stand Alone hybrid power system to balance the voltage profile. Authors have mentioned number of processes like the use of capacitor banks for compensation of reactive power of the system [6]-[8].But due to the uncertain nature of wind and wide variation of load the fixed capacitors failed to deliver the required reactive power to the system. [7]. Due to the above said reasons the FACTS(Flexible AC Transmission System) devices are widely used for the compensation of reactive power now a days. Devices like SVC, STATCOM and UPFC are quite popular in controlling and compensating reactive power. [9]-[11].

SVC, STATCOM and UPFC [12]–[16] are important members of FACTS family which are used to compensate the reactive power of the power system. These devices are used for voltage and angle stability studies of power system. Reactive power management inside the hybrid system is an important aspect of power system and during the absence of reactive power; the system goes through a wide voltage variations and unnecessary fluctuations. devices as a reactive power compensating devices with PI controllers. This work proposes a fuzzified PI based controller for SVC, STATCOM and UPFC Controllers for reactive power control in a wind diesel hybrid system [17]-[21]. The proposed controller tunes the gains of the PI Controller to enhance the transient stability and reactive power compensating capability of the system

This paper represents a MATLAB/SIMULINK model briefing the Reactive Power Compensation of an Isolated Wind-Diesel hybrid System with application of SVC for 2 % change in load disturbances. Section no II completely describes the system and the detailed mathematical modeling of it. The detailed work of self tuned fuzzy logic for tuning the gains of PI controller is mentioned in Section III. The model simulation output results with description are represented in section IV. The conclusion is clearly mentioned in Section V.

II. SYSTEM CONFIGURAION AND ITS MATHEMATICAL MODELLING

This hybrid power system is made of Induction generator (IG), Synchronous generator (SG), electrical loads and Reactive power control in the form of SVC supported by its control strategy. A general block-diagram of the system is clearly shown in Fig. 1.Generally the Synchronous Generator and the Induction generator supply the active power to the system.Sychronous Generator and SVC also provide the reactive power to the load and Induction generator. The hybrid system parameters are given in Table3 in Appendix gives the total parameters of the hybrid system.

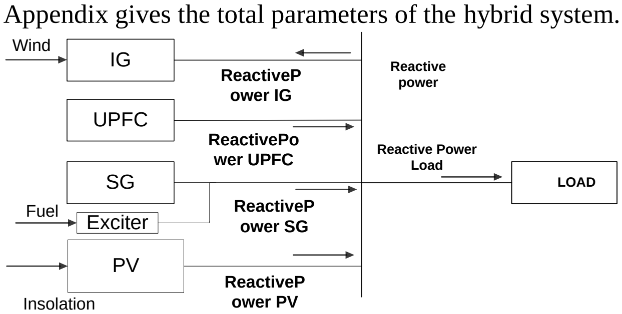


Fig. 1. Wind-diesel-pv hybrid Power system with UPFC

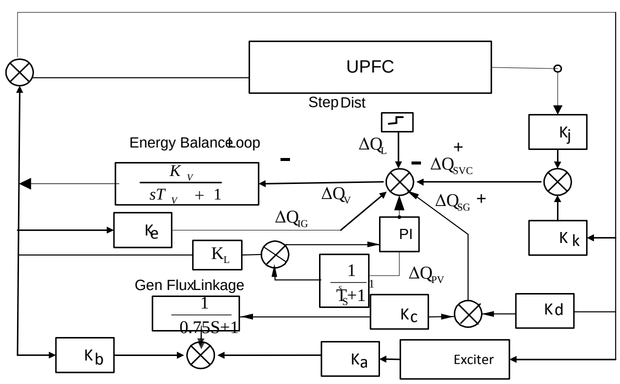


Fig. 2. Transfer Function Model of Wind Diesel PV Hybrid Power System with UPFC

The Reactive Power balanced Equation of the system during steady state can be given by [13]

$\Delta Q_{SG} + \Delta Q_{svc} + \Delta Q_{PV} = \Delta Q_L + \Delta Q_{IG}$ (1)

Due to abrupt change in reactive power load ΔQ_L , the system voltage may change which results incremental change in reactive power of other components. The net reactive power is $\Delta Q_{SG} + \Delta Q_{SVC} + \Delta Q_{PV} - \Delta Q_L - \Delta Q_{IG}$ and it will change the system voltage. The System Model Equation is governed by the transfer function equation given below [14]

$P_{IG}+P_{SG}+P_{PV}=P_L$
(2)

$Q_{SG} + Q_{COM}+Q_{PV} = Q_L + Q_{IG}$
(3)

$\Delta V(S)= K_V/ (1+ST_V)[\Delta Q_{SG}(S)+\Delta Q_{PV}(S)+\Delta Q_{COM}(S)-\Delta Q_L(S)-Q_{IG}(S)$ (4)

Where $T_V= 2H_r/ D_V V^0$ and $K_V= 1/D_V$

The synchronous generator equation is given by :

$Q_{SG}= (E'qV\cos\delta - V^2) / X'd$ (transient condition) (5)

For small change the same equation is written as

$\Delta Q_{SG}= V \cos\delta /X'd \, \Delta E'q+(E'q\cos\delta -2V)/X'd \, \Delta V$ (6)

Taking the Laplace Equation we get the relation

$\Delta Q_{SG}(s) = K_{a1} \Delta E'q(s) + K_{b1}\Delta V(s)$
(7)

Where K_{a1} and K_{b1} are

$K_{a1}= V\cos\delta /X'd$

$K_{b1}=(E'q\cos\delta -2V)/X'd$

UPFC provides the reactive power required by the load and the Induction Generator.

For a Round Rotor Synchronous Motor the Flux Linkage Equation

$d/dt (\Delta Eq')=(\Delta E_{fd} -\Delta Eq)/T'do$ (12)

$Eq =(Xd/X'd)E'q-(Xd-X'd)/X'dV\cos(\delta)$ (13)

For Small Perturbation Laplace Transform is written as

$(1+ sT_G) \Delta E'q (s) = Ke\Delta Efd (s) + K_f \Delta V(s)$ (14)

Where $T_G=X'_dT' do /Xd$

$K_{e1}=X'_d/X_d$

$K_{f1}=(X_d-X'_d)\cos\delta/X_d$

The Reactive power need of the Induction Generator is fulfilled by the UPFC .The demand of Reactive Power changes with the change of wind speed. SIMULINK model using reactive power compensator UPFC is designed for the Hybrid System. For the SVC compensator gain regulator K_R scheme is used for control mechanism [14]. In case of UPFC the small change in reactive power [15] depends on V_{m2p} and angle δ which are proportional to the voltage at the point of connection of UPFC.

Unified Power Flow Controller (UPFC) is for Reactive power compensation like SVC and STATCOM whose transient stability model is shown in Fig. 3. .It controls the power flow in the transmission system by controlling the impedance, voltage magnitude and phase angle. This controller offers advantages in terms of static and dynamic operation of the power system. The structure of the UPFC consists of two voltage source inverter (VSI), where one Voltage source converter is connected in parallel to the transmission line while the other is in series with the transmission line.

The Structure of UPFC helps to control Reactive power and Active Power by injecting AC Voltage in series with amplitude and a phase angle to the Transmission Line. The role of first Inverter is to provide or absorb real power while the second Inverter produces and absorbs reactive power and there by provides shunt compensation. It has been assumed that the series and shunt impedances of UPFC are pure reactances. P_{sh} and Q_{sh} are with the shunt voltage sources while *Pi*, *Qi*, *Pj* and *Qj* represent the series voltage sources. The injected powers depend on the injected voltages and bus voltages also. Buses *i* and *j* are taken as load buses in the load flow analysis .They are taken with some modifications as the injected powers are not constant. The injected powers are given as follow:

$$P_{sh} = \frac{V_i V_{sh}}{x_{sh}} \sin(\delta_i - \delta_{sh}) \quad (19)$$

$$Q_{sh} = \frac{V_i^2}{x_{sh}} - \frac{V_i V_{sh}}{x_{sh}} \cos(\delta_i - \delta_{sh}) \quad (20)$$

$$P_i = \frac{-V_i V_{pq}}{x_{ij}} \sin(\delta_i - \delta_{pq}) \quad Q_i = \frac{V_i V_{pq}}{x_{ij}} \cos(\delta_i - \delta_{pq}) \quad (21)$$

$$P_j = \frac{V_J V_{pq}}{x_{ij}} \sin(\delta_j - \delta_{pq}) \quad (22)$$

$$Q_j = \frac{-V_j V_{pq}}{x_{ij}} \cos(\delta_j - \delta_{pq})$$

Multiplying V_j to the above two equations we can get

$$P_j = \frac{V_i V_j}{x_{ij}} \sin\delta - \frac{V_j V_{m2p}}{x_{ij}} \quad (23)$$

$$Q_j = \frac{V_i V_j}{x_{ij}} \cos\delta - \frac{V_j V_{m2q}}{x_{ij}} - \frac{V_j^2}{x_{ij}} \quad (24)$$

$V_{m2p}=V_j\gamma(t)$ and $V_{m2q}=V_j\beta(t)$ where $\gamma(t)$ and $\beta(t)$ are control variables.

Taking the partial derivative we get

$$\frac{dP_j}{dt} = \frac{dP_j}{d\delta}\frac{d\delta}{dt} + \frac{dP_j}{dV_{m2p}}\frac{dV_{m2p}}{dt} \quad (25)$$

$$\frac{dQ_j}{dt} = \frac{dQ_j}{d\delta}\frac{d\delta}{dt} + \frac{dQ_j}{dV_{m2p}}\frac{dV_{m2p}}{dt} \quad (26)$$

$$\Delta Q_{UPFC} = K_j\ \Delta\delta(S) + K_k \Delta V(S)$$

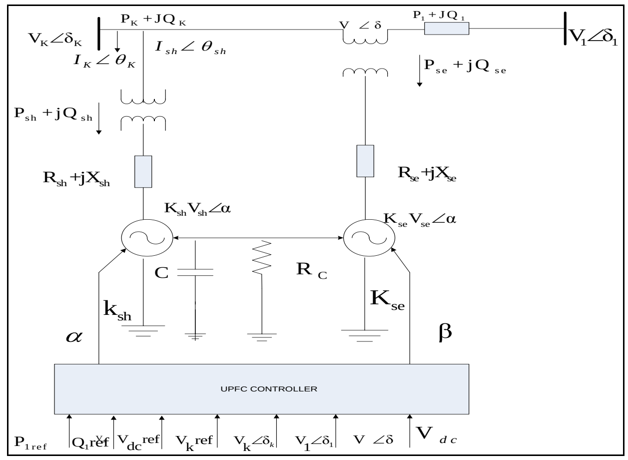


Fig. 3 Transient Stability Model UPFC

III. FUZZY LOGIC CONTROLLER (FLC)

Fuzzy logic is a knowledge based controller based on self-organizing architecture which is having a lot of applications in power system dynamics and control applications [17]. A fuzzy system consists of fuzzy IF-THEN rules and membership functions . The reactive power control problem to regulate the voltage of the wind-diesel hybrid system considered here is studied under small sudden disturbances in connected load.

3.1 Self-Tuning Fuzzy PI Controller

The proposed Auto tuned Fuzzy logic PI controller is designed based on the concept of PI controller.

$U(s) = KpE(s) + Ki \int E(s)$ (16)

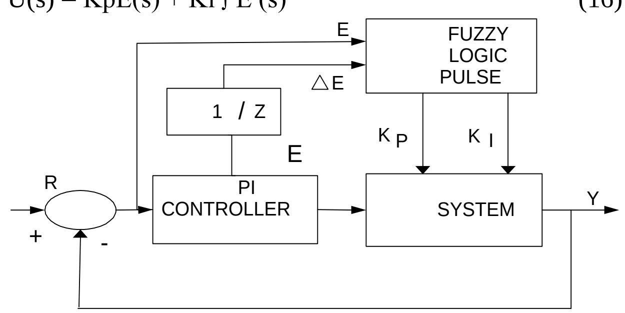


Fig. 4.Fuzzy PI controller Block

$E^*Kp + Ki^* \int E = U$ (17)

The system performance can be improved by Changing the value of parameters Kp and Ki of the PI controller. The PI parameters (Kp and Ki) are slowly changed using fuzzy inference engine. This provides a mapping which is not linear with having inputs as error and change in error and ouputmKp and Ki. Fig 4 shows the block having Fuzzy PIController.

μPi = min (μ(E), μ(ΔE))

μIi = min (μ(E), μ(ΔE))

The rules that are mentioned in the table 1 & 2 are made taking the voltage variation of system in diesel side and daviation of wind energy (ΔPGW) in wind side to improve the system performance. Two input variables, error (Δv) and change in error(Δv)' and two output variables Kp and Ki of the PI controller with seven linguistic variables of Triangular membership function is used for the proposed self tuning Fuzzy logic PI controller. The input membership functions are error(E) and change in error(ΔE) and output membership functions are Kp and Ki.

Table 1 Fuzzy rule for Kp

E/ΔE	NL	NM	NS	Z	PS	PM	PL
NL	VL	VL	VB	VB	MB	M	M
NM	VL	VL	VB	MB	MB	M	MS
NS	VB	VB	VB	MB	M	M	MS
Z	VB	VB	MB	M	MS	VS	VS
PS	MB	MB	M	MS	MS	VS	VS
PM	VB	MB	M	MS	VS	VS	Z
PL	M	MS	VS	VS	VS	Z	Z

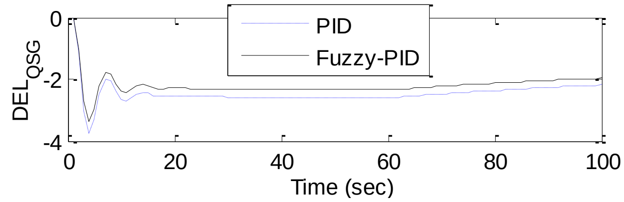
Table 2 Fuzzy rule for Ki

E/ΔE	NL	NM	NS	Z	PS	PM	PL
NL	Z	Z	VS	VS	MS	M	M
NM	Z	Z	VS	MS	MS	M	M
NS	Z	VS	MS	MS	M	MB	MB
Z	VS	VS	MS	M	MB	VB	VB
PS	VS	MS	M	MB	MB	VB	VL
PM	M	M	MB	MB	VB	VL	VL
PL	M	M	MB	VB	VB	VL	VL

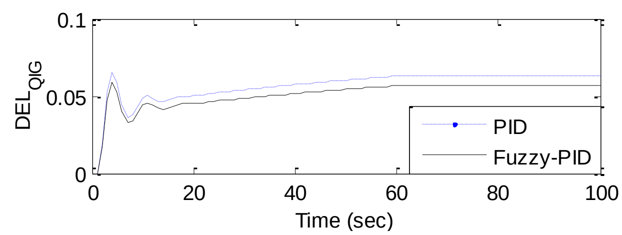
IV. SIMULATION RESULTS

The complete Simulation was carried away taking the Fuzzy Logic PI Controller in the wind diesel hybrid power system in MATLAB/Simulink environment. Application of STFLPI controller for reactive power and voltage control of the isolated hybrid system was taken with a step load change of 2%. The variation of all the system parameters such as small variation in reactive power of Synchronous generator(ΔQ_{SG}),Induction generator(ΔQ_{IG}),UPFC (ΔQ_{UPFC}), Variation in firing angle($\Delta Q\alpha$),Variation in terminal voltage(ΔV),Variation in field excitation(ΔE_{fd}), Variation in armature voltage(ΔE_q),and change of armature voltage under transient($\Delta E'_q$), etc., as shown in Fig. 5, are studied for the above mentioned disturbance using traditional PI Controller and the advanced Fuzzy PI Controller.

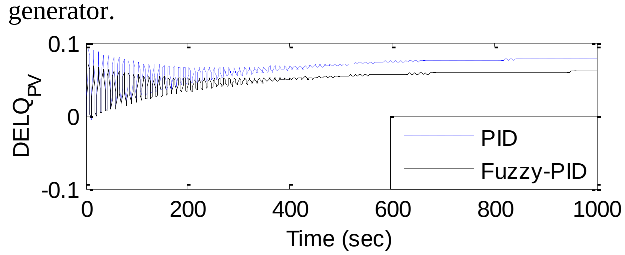
In the study, it is observed that the controllers provide better performance with the increase of size of synchronous generator in comparison to the size of Induction generator to achieve good control of terminal voltage. Also the firing angle change of TCR in UPFC improves with the decrease in the value wind power output. But they settle at different points. The settling time and peak overshoot in the case of STFLPI controller is observed to be less as comparison to traditional PI Controller. The (FLC) shows better result by increasing the diesel power generation. Simulation results clearly show the output of Fuzzy PI Controller is better than the traditional PI Controller.



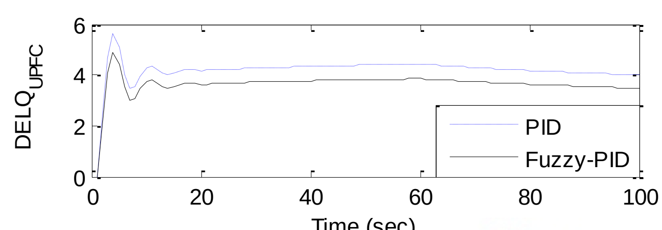
(a) Change in Reactive power of diesel generator.



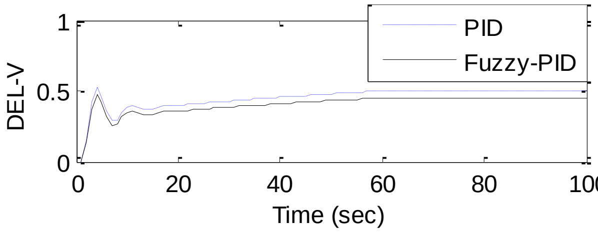
(b) Change in Reactive power of induction generator.



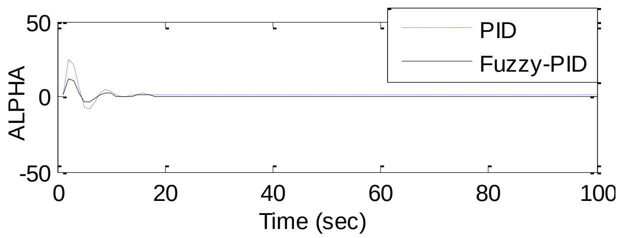
(c) Change in Reactive power of photovoltaic (PV).



(d) Change in Reactive power of UPFC.



(e) Change in Terminal voltage of wind-diesel system.



(f) Change in Firing angle of thyristor.

Fig. 3. Output of Wind Diesel hybrid system using SVC for 2 % load change during transient condition.

V. CONCLUSIONS

In this paper, the self tuning Fuzzy PI controller has been incorporated for automatic Reactive Power control of an isolated wind-diesel hybrid power system. After comparing the performances in the proposed paper a conclusion can be drawn that the response about the Reactive Power Control in the proposed system with the application of self tuning FuzzyPI controller has a shorter settling time. The results obtained by using self tuning FLPI controller proposed in this paper is better than the system having conventional PI controller with regard to settling time and overshoot . The proposed controller is effective and provides noticeable improvement in system performance by tuning the parameters Kp and Ki of PI controller. The proposed controller maintains its robustness and proves its strength under large disturbances.

NOMENCLATURE

P_{IG} = Real power generated (Wind Turbine)

P_{SG} = Real power generated (Diesel System)

P_L = Real power (load demand)

Q_{SG} = Reactive Power generated by Diesel

ΔQ_{SG} =Change in reactive power generated by Diesel generator

Q_{COM} = Reactive power Generated by Compensator

X_d =Change in reactive power generated by Compensator

Q_L = Reactive power generated by Load

ΔQ_L =Change in reactive power generated by load.

Q_{IG} = Reactive power generated by Induction Generator

ΔQ_{IG} =Change in reactive power generated by induction generator.

$\Delta E_q'$ =Change in Internal Armature Emf in proportion with change in direct axis field flux in transient case.

ΔB_{SVC} = Change in Susceptance of the SVC

$\Delta\alpha$ = Change in the phase angle at SVC output

ΔV = Change in voltage at load.

ΔQ_{pv} =Change in reactive power given by PV

ΔQ_{UPFC} =Chenge in reactive power of UPFC

Appendix

Table 3- Parameters of wind-diesel hybrid system

System Parameter	Wind Diesel System
Wind Capacity (Kilowatt)	150
Diesel Capacity	150
Load Capacity	250
Base Power in KVA	250
SYNCHRONOUS GENERATOR	
P_{SG}, KW	0.4
Q_{SG} KW	0.2
E_q(pu)	1.113
E_q'(pu)	0.96
V(pu)	1.0
X_d,(pu)	1.0
T'_{do},s	5
INDUCTION GENERATOR	0.6
P_{IG},pu in Kilowatts	
Q_{IG},pu in KVAR	0.189
P_{IN},pu in Kilowatts	0.75
r1=r2(pu)	0.19
X1=X2(pu)	0.56
LOAD	1.0
P_L(pu) in KW	
Q_L(pu) in KVAR	0.75
α in Radian	2.44
UPFC	
T_α (S)	0.05
T_d,s	5.044
	0.3

X_d	

REFERENCES

[1] H.Nacfaire, "Wind-Diesel & Wind Autonomous Energy Systems", *Elsevier Applied Science*, 1989.

[2] S.A.Papathanassiou, M.P.Papadopoulos, "Dynamic characteristic of autonomous wind diesel system", *Renewable Energy* 2001.

[3] T K Saha, D Kasta"Design optimisation & Dynamic performance analysis of Electrical Power Generation System" *IEEE Transaction on Energy Conversion Device*, 2010.

[4] PK Sandhu and JK Chatterjee " Three Phase Induction Generator", *Discussion on performance Electrical Machine Power System*, vol 27,no 8,Aug 1999.

[5] AK Tondon,SS Murthy,GJ Berg,"Steady state analysis of capacitors Excited Induction Generators",*IEEE Transaction on Power Apparatus & Systems*,March 1984.

[6] RCBansal,"Three phase self Excited Induction Generators, an over view",*IEEE Transaction on Energy Conversion* ,2005.

[7] SE Haque,NH Malick and W Sephard "Operation of a Fixed Capacitor Thyristor Controlled Reactor Power Factor Compensator",*IEEE Transaction of Power Apparatus and System*,july1985.

[8] SS Murthy ,OP Malik and AK Tondon, "Analysis of Self Excited Induction Generator" *IEE Proceeding* , vol 129,Nov 1982.

[9] KRPadiyar,"FACTSControllerin Power Transmission and Distribution",*NewAge International Publishers* , 2008 .

[10]NGHingorani,LGyugyi,"UnderstandingFACTS,Concepts and Technology of Flexible AC Transmission System",NewYork,*IEEEPowerEngineering Society*,2000.

[11] AE Hammad and M El Sadek"Application of Thyristor Controlled Var Compensator for damping Sub Synchronous oscillation in Power System"*IEEE Transaction Power App System*,jan 1984.

[12] R C Bansal"Automatic Reactive Power Control of Autonomous Hybrid Power System"*PhD Thesis ,Centre for Energy Studies*, IIT Delhi December 2002.

[13] P Balsubhramaniam, AS Murthy & P Parameswaram, "Design of variable structure controller for static VAR compensator", *Electr. Mach Power System* , May 1998.

[14] K R Padiyar, RK Verma,"Damping Torque Analysis of Static VAR System controller",*IEEE Transaction of Power System*,vol 6.No2, PP458-465,May 1991.

[15] RC Bansal, TS Bhatti, V Kumar," Reactive Power Control of Autonomous Wind Diesel hybrid Power System using ANN", *Proceeding of the IEEE Power Engineering Conference*(2007).

[16] Francisco Juardo and Jose R Saenz,"Neuro Fuzzy Control for Autonomous Wind Diesel System using Biomass", *Renewable Energy* ,Vol 2 .2002 .

[17] P.Sharma, T.S.Bhatti and K.S.S.Ramakrishna,"Study of an Isolated Wind Diesel hybrid power system with STATCOM by incorporating a new mathematical model of PMIG"*European Transactions.Electric Power* 10.1002/etep 566 to be published.

[18] Y.H.Songand A.T.Johns,"Flexible A.C.Transmission Systems(FACTS)",*IEE Power and Energy Series* 30,London,UK:Inst.Elect.Eng.1998.

[19] B.Kouadri,Y.Tahir,"Power flow and transient stability modeling of 12-Pulse statcom," *J.Cybem.Inform* . vol7,pp 9-25, 2008 .

[20] A.Yazdani, H.Sepahyand, M.L.Crow,Ferdowsi"Fault detection and mitigation in Multi Level Converter STATCOM"*Electron*,vol.58.no4.pp.1307-1315,Apr.2011.